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The districts of Lithuania with low heat demand density: A chance for the integration of straw biomass

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ABSTRACT

District heating sector is one of the most important sectors of Lithuanian energy industry. Consequently, low-cost bioenergy sources could play an important role in developing biofuels based on the so-called second-generation feedstock and decentralized energy supply for remote rural areas with low heat demand density. The present amount of biomass straw is already considerable in Lithuania but the potential is even much higher. It is assumed that the share of firewood in the balance of RES will decrease significantly – from 86.7% in 2009 to 55% in 2020 and future decisions on the acceptability of new substitutes must be found. The most important factors that could hasten the diffusion of straw combustion technologies for heat-only boilers (HOBs) in order to contribute to a local fuel and low-emission energy infrastructure are political issues, reduction in existing technical thresholds, market and economic conditions, international cooperation activity, and broad experience through wood residue combustion.

The collected data indicated that under conditions in Lithuania, biomass straw combustion is prospective mainly to be used for heat production in small and medium scale units of 0.6–5.0 MW_{th} capacity as well as in large scale installations where multi-biomass strategies are foreseen.

Contents

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1. Introduction

Like many countries, Lithuania is facing challenges in the energy sector in three main dimensions: energy independence, competitiveness and sustainability of the energy sector [1]. In this respect, the critical dependence on imported fuels hold on Lithuania's energy future must be emphasized. Imported fuels are dominated by oil (2.9 mill. t), natural gas (2.5 mtoe), and coal (0.2 mtoe), thus altogether comprising a significant part among commercially traded fuels, which is 8.2 mtoe in 2009 (excluded, therefore, are fuels such as wood, peat, animal waste, geothermal and solar power generation) [2].

Consequently, low-cost bioenergy sources could play an important future role in developing biofuels based on the so-called second-generation feedstock and decentralized energy supply concepts for remote rural areas. The 27 member countries of the European Union acknowledge the multifunctional role of the primary sector; however each of them emphasizes specific functions according to its own model of agriculture and rural development [3].

Traditionally, the agriculture and food sector have been very important for the Lithuanian economy. For the last decade, agriculture has been showing positive trends of growth of production volumes and attraction of investments. The sector provides a large number of jobs and about 50% of the country's gross national product (approx. 3.37 million ha of land are used for agricultural production) [4]. Consequently, many regions in Lithuania have abundant resources of low-grade fuel, i.e. straw, which can be explored locally at low cost, using local labor and thus saving import of expensive fuels [5].

2. Current status of renewable energy use in Lithuania

The share of RES in total primary energy supply in Lithuania is approximately of 0.87 mtoe (Fig. 1). Comprising 18.38% of final energy produced, it supplied 17% (~0.81 mtoe) of countrywide (rural and urban) energy consumption in 2009, which is ~4.77 mtoe.

Basic biomass sources are comprised of wood (~0.76 mtoe), liquid biofuel (52.3 ktoe), agricultural waste (4.2 ktoe), and biogas (4.7 ktoe) [6]. The biggest share of RES, i.e. 86.7% accounts for solid biomass, mainly firewood and wood waste. 57.3% of wood-for-fuel being consumed by direct-combustion in the household sector. Currently, only agricultural waste biomass (1.85%), and firewood and wood waste (98.15%) are used as a biofuel for DH plants, with the thermal energy output of 0.14–0.15 mtoe. The implication is that the most of attention in Lithuania is given to issues related to wood fuel production and use. However, total amount of this traditional source of biomass used for energy generation is limited by forest management planning [7]. It is assumed that the share of firewood in the balance of RES will decrease significantly – from 86.7% in 2009 to 55% in 2020 [8,9] and future decisions on the acceptability of new substitutes must be found.

Considerable part of wood, especially residues from saw-mills, is already used for heating purposes however, significant amount of forestry and agricultural residues are still not collected [10]. Wheat and barley straw as a low-grade fuel is one of the abundant lignocellulosic crop residues in Europe. In Lithuania, agriculture produces approximately 1.5–2.0 million t of straw each year for olericulture, litter and animal feed. An increasing proportion of straw quite often undergoes the in situ field burning as well. This waste of energy sources seems inapt and unjustifiable in the light of the great demand for reducing greenhouse gas emissions, high fuel prices, air pollution and Country's energy independence. To make biomass available for the proposed increases in primary energy mix, straw and energy plantations should be introduced. Estimated annual use of straw is 900,000 t/year in 2020, equivalent to 35% of total straw production [10].

3. Technological peculiarities of straw conversion to energy

3.1. Physical-chemical characteristics and standardization of biomass straw

Straw is a fuel available locally in any agricultural zone. Straw, the stalks remaining after the harvest of grain, is renewable resource, grown annually in Lithuania. Collected site-specific data on elementary composition and calorific value of biomass straw [11] have shown a close correlation to the findings by researchers in the European countries and elsewhere [12–16]. In the case of using of crop residues as a fuel for heat-only boilers (HOBs), chemical composition and calorific value of biomass straw depends to a large extent on a time period it was exposed to field conditions [17], rather than on cultivation method or soil properties (which practically could not be controlled by the end consumer). The crop residues that has been lying in the swath and has been exposed to rain and dew ('grey straw') has a reduced content of troublesome elements: sulfur, corrosive matter and chlorine (Table 1). As reported in [11], under conditions in Lithuania, the 'grey straw' are distinguished for a higher rates of lower heating value (LHV) and higher heating value (HHV) comprising 3% and 5% respectively. The 'grey straw' is more lenient to the boiler, since part of the chemical elements and their compounds that induce corrosion of the boiler walls and tubes has been removed, when the 'yellow straw' collected and baled straight away after combine harvest may cause slagging, fouling and possibly increase corrosion in furnaces [18].

The European Committee for Standardization (CEN) draws up voluntary technical specifications for solid biofuels to help achieve a single European market, promoting the welfare of citizens and sustainable development [19,20]. Currently, only bales of rectangular cross section are specified (Table 2) [19–21]. Principle of the baled straw quality assurance is based on its clearly defined determination and limited demand for product. It is substantial for both small and big consumers. The purpose of quality classification and specification of baled straw is to determine their quality within the whole supply chain from origin until the certificated delivery as well as to assure corresponding confidence to the qualitative requirements [21]. This is the basis for pre-market preparation and its further development in Lithuania. In fact, manufacturer and customer can agree with a certain characteristics for each simple case [21].

3.2. Environmental aspects, deposits and corrosion during straw combustion

There have been many scientific papers [22–25] and book chapters [26] outlining that approximately 90% of the carbon released during straw burning is oxidized to CO_2 or CO, with typically less than 5% of the carbon being released as particulate matter. In burning facilities, especially grate-fired boilers, the incomplete combustion process also gives rise to higher emissions of polyaromatic hydrocarbons (PAH), CO, hydrocarbons (C_nH_m) and NO_X [22–24,26]. Accordingly, the design of grate assembly and primary/secondary air supply systems split ratio 40/60 [22] plays a crucial role in the efficient and clean combustion of straw.

The firing of almost any type of solid biofuel like wood materials or crop residues, straw combustion utilities may suffer from severe deposition and corrosion problems as well. Deposits reduce both the overall process efficiency and the heat transfer in the boiler, while corrosion reduces the lifetime of the installation [22,23,26].

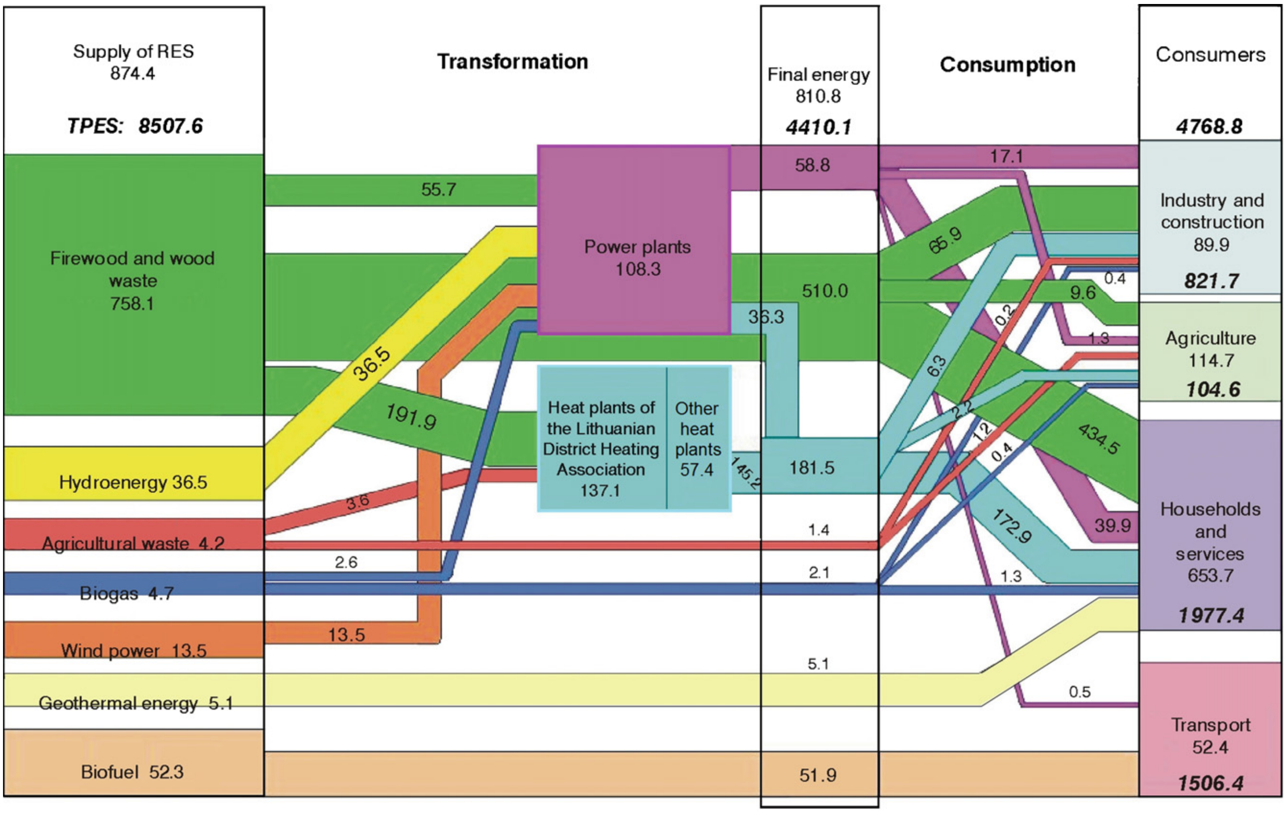

Fig. 1. Renewable energy resources flows in Lithuania in 2009.

Distribution of the combustion-relevant elements concentration in the temperature range of 1000–1200 °C typical for straw-firing utilities is presented in Table 3.

Straw have low contents of Ca and high contents of K and Si in ash [22–28]. In the case of Ca, an increase in temperature has no effect on slag formation; only an accession of solid state (5.5–7.5%) is observed, particularly an appearance of calcium phosphate (18%).

The share of K release to the gas phase at 1000 °C in the form of KCl is approximately 42% against the sum of KCl and KOH, which comprise 52% of total K at 1200 °C [27]. Slag formation (K_2O) seems to be reduced by 15.5% at 1200 °C. Nevertheless, this effect could not poise the drastic increase (19%) in KCl formation. The mole fraction of KCl going to gas phase increases with temperature [28], and the same trend is also observed for sulfur dioxide (SO_2). In the case of biomass straw combustion at 1000 °C, 2% of S could be found in the slag. For both temperature ranges, sulfur is mainly present as SO_2 and SO_3 and evolved into the gas phase.

During straw combustion in a grate furnace, sodium chloride (NaCl) is readily formed by the combination of a strong acid (HCl) and strong base (NaOH) and varies from 3% of total Cl at 1000 °C to 4% at 1200 °C [27]. The bigger influence on temperature is observed for metal halide salt composed of potassium and chloride. Together with temperature increment of 200 °C, an obvious increase in KCl content (20.5% of total Cl) is also observed. Need to denote that higher combustion temperature positively affects on hydrochloric acid (HCl) formation process, thus reducing it by 39.5%.

A temperature increase has also an impact on solid phase reduction for silicon that decreases in 5.5–7.0% (% of total Si) as well as marginal increase of 3.2% in silicate melt [27].

To solve high-temperature reactions in ash effectively, the anti-sintering additives like dolomite and kaolin could be used. Dolomite added to wheat and barley ash reacts with silicon dioxide to form silicates. As described in [29], the reaction between potassium chloride (KCl), sodium chloride (NaCl) and K_2SO_4 in straw ash and kaolin showed that several end products are possible, like $KAlSiO_4$ and $KAlSi_2O_6$.

4. Strengthening and weakening factors affecting straw introduction

As it is seen in Fig. 2, there is a large amount of strengthening and weakening factors affecting introduction of straw-for-HOBs in Lithuania.

Previous studies on the transformation of the energy system have demonstrated that the success of renewable energy technologies is not only determined by technical and economic factors (such as technical performance or the relative price of the technology),

Table 1
A collation of the elementary composition of "Grey" and "Yellow" straw of barley [11].

Type of straw	Moisture content, %	Ash melting temperature, °C	HHV, MJ/kg	LHV, MJ/kg	Elementary composition, %						
					C	H	O	N	S	Cl	Ash
"Yellow" (1 day in the swath)	10–20	800–1000	18.2	14.4	42	5.0	37	0.35	0.16	0.75	4
"Grey" (22 days in the swath)	10–20	950–1100	18.7	15.0	43	5.2	38	0.41	0.13	0.2	3

Table 2
Specification of properties for straw bales.

1. Coreal crop straw			
2 Grass straw			
3 Oil seed crops stalks and leaves			
Normative parameters			
Forms of trade: Rectangular Bale			
Dimensions (mm): height (L_1), width (L_2), and length (L_3)			
	Height (L_1)	**Width (L_2)**	**Length (L_3)**
P1	1300	1200	2200
P2	1300	1200	2400
P3	600–900	1200	2400
P4	1300	1200	1100–2750
Bale density (kg/m^3)			
BD130	≤135		
BD150	≤150		
BD165	≤165		
BD165+	>165		
Moisture (wt.% as received)			
M16	≤16%	No part over 23%	
M16+	≤16%	Parts over 23% acceptable	
M23	≤23%	No part over 30%	
M23+	≤23%	One or more parts over 30%	
M30	≤30%	No part over 35%	
M30+	≤30%	One or more parts over 35%	
Ash (wt.% of dry basis)			
A05	≤5%		
A10	≤10%		
A10+	>10%		
Informative parameters			
Net calorific value, $q_{p,net,ar}$ (MJ/kg as received or energy density E_{ar} (kW h/m^3 loose))			Recommended to be specified [19–21]
Particle size distribution or structure			It is recommended to declare production methods that influence the size of the straw particles. That is for instance whether the crop has been trashed by rotation or oscillation, or whether it has been chopped [19–21].

but also by the social system in which the technology is embedded [30,31].

The most important factors that could hasten the diffusion of straw combustion technologies for HOBs in order to contribute to a local fuel and low-emission energy infrastructure are political issues – government interest in small scale, reduction in existing technical thresholds (see Fig. 2), market and economic conditions for successful implementation – low prices for feedstock and high prices for natural gas, international cooperation activity, and reduction in fossil fuel share jointly with the broad experience gathered through wood residue combustion in HOBs. It was reported [31], these are all factors that play a role when the technology is still in a niche market and needs to breakthrough. To further reduce perceived uncertainties within a niche market, governmental policy should therefore aim at mobilizing sufficient risk capital, i.e. creating favorable conditions for private investors [31].

Concerning strengthening factors, there is no reason why agriculture's gross domestic product share could not remain constant or even increase, if the sector were to embark on a path of rapid reform or restructuring in the future. This might slow but would likely not reverse the decline in agricultural production (grain, oilseed crop, etc.) share. The movement of labor from traditional agriculture to the manufacturing and service sectors need not mean that agriculture is stagnant and incapable of growth.

5. Methodological approach

An extensive review of R&D projects, scientific publications, Lithuania‘s energy policy documents, relevant books, journals, reports, and case studies from Lithuania and elsewhere in the developing world [32–38] as well as information from Lithuanian Biomass Energy Association, the Lithuanian District Heating Association, Ministry of Energy of the Republic of Lithuania, and local companies provided the basis for objective review. Balance of available biomass straw at national level was based on statistical data.

The economic evaluation with particular attention to economic cost-benefit analysis (CBA) was introduced in details. Currently, CBA methodology has not been normalized in national or international standards [39]. The general procedure for a CBA is as follows: definitions of the system boundaries of the analyzed activity; quantification of activity-based inputs and outputs for the entire time frame laid down by system boundary; determination of the appropriate discount rate for assessing future activity inputs and outputs on a consistent basis; calculation of indicators; evaluation (Table 4).

Data collected in any of the ways described above can then be processed in order to provide useful information about the untapped opportunities to combust straw in heat-only boilers, under the scenario of small agrarian country having a large number of districts with low heat demand density. The following sections present the basic processing methods.

6. System perspectives on straw bioenergy

6.1. Administrative division of Lithuania

The current country's administrative division was created in 1994 and modified in 2000. Lithuania is divided into:

- 10 counties – each named after their principal city: Alytus county (Hierarchical administrative subdivision code: LT.AS; area:

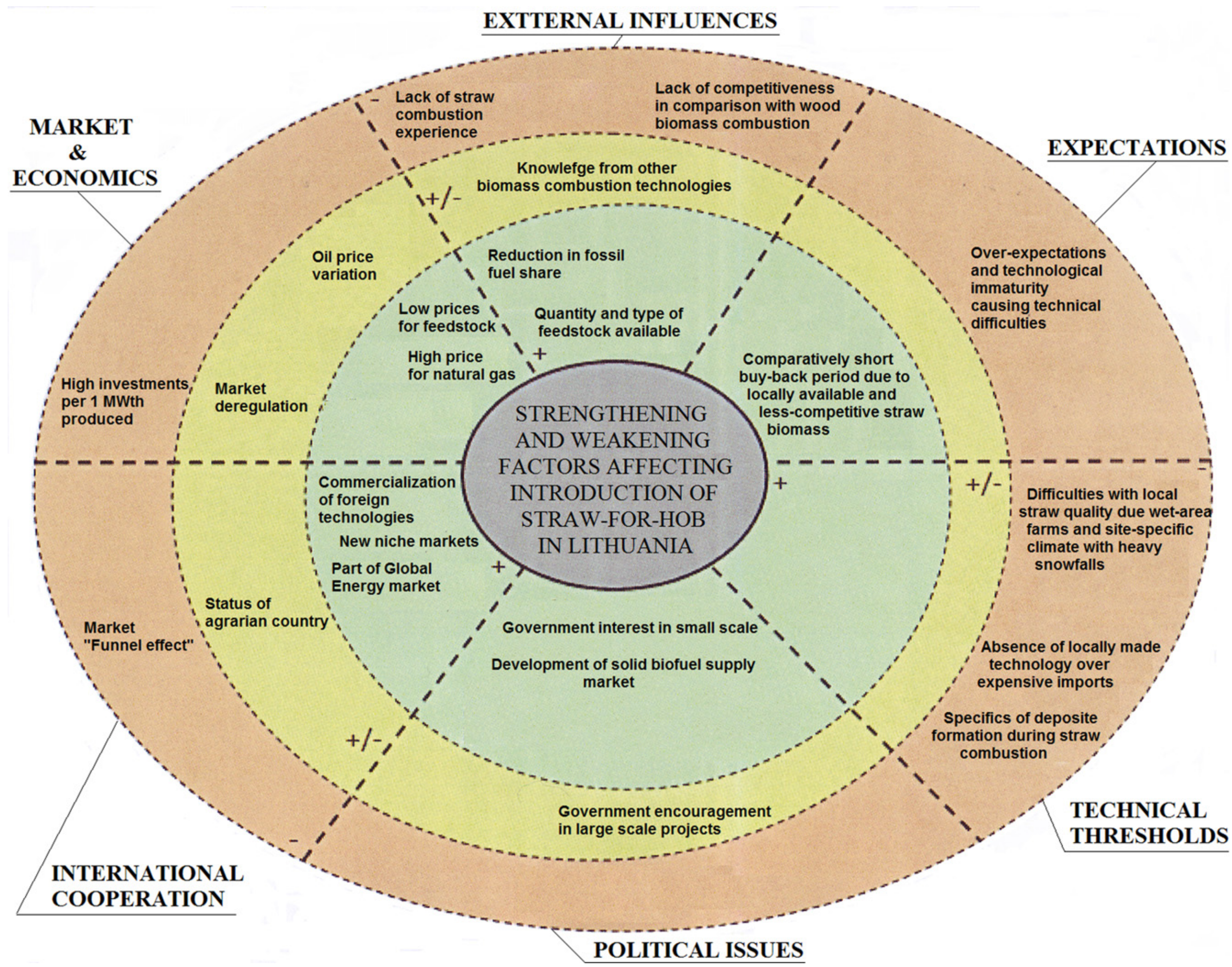

Fig. 2. Strengthening and weakening factors affecting introduction of straw-for-HOBs.

5425 km^2), Kaunas county (LT.KS; 8089 km^2), Klaipėda county (LT.KP; 5209 km^2), Marijampolė county (LT.MA; 4463 km^2), Panevėžys county (LT.PA; 7881 km^2), Šiauliai county (LT.SH; 8540 km^2), Tauragė county (LT.TG; 4411 km^2), Telšiai county (LT.TE; 4350 km^2), Utena county (LT.UN; 7201 km^2) and Vilnius county (LT.VI; 9731 km^2).

- The counties are subdivided into 60 municipalities. There are three types of municipalities:
  - 43 district municipalities (see Fig. 3). Before 1994 they were known just as districts and still are commonly referred to as districts (the word 'municipality' was added in effort to diminish the Soviet heritage);
  - 9 municipalities (see Fig. 3). They were all established after 1994 and they do not have the word 'district' associated with them;
  - 9 city municipalities. They are situated around major or important cities. In common language they are referred to as just cities (Alytus city, Kaunas city, Klaipėda city, Palanga city, Panevėžys city, Šiauliai city, Vilnius city and Visaginas city).
- The municipalities consist of over 500 elderships.

Table 3
Distribution of Cl, K, Ca, Si, and S (mole-%) during straw biomass combustion in the furnace-boiler facility at 1000–1200 °C (minor phases have been neglected, thus, the sum is not always equal 100%) [27].

T (°C)	Cl (% of total Cl)	K (% of total K)	Ca (% of total Ca)	Si (% of total Si)	S (% of total S)
1000	63% as KCl (gaseous) 33% as HCl (gaseous) 3% as NaCl (gaseous)	42% as KCl (gaseous) 57% as K_2O (slag/silicate melt)	43% as $CaSiO_3$ (solid) 37% as $CaMgSi_2O_6$ (solid) 6% as $Ca_3(PO_4)_2$ (solid) 7% as CaO (slag/silicate melt)	23% as $CaMgSi_2O_6$ (solid) 13% as $CaSiO_3$ (solid) 63% as SiO_2 (slag/silicate melt)	95% as SO_2 (gaseous) 2% as SO_3 (gaseous) 2% as K_2SO_4 (slag/silicate melt) 0.5% as K_2SO_4 (gaseous)
1200	76% as KCl (gaseous) 20% as HCl (gaseous) 4% as NaCl (gaseous)	50% as KCl (gaseous) 2% as KOH (gaseous) 48% as K_2O (slag/silicate melt)	40% as $CaSiO_3$ (solid) 35% as $CaMgSi_2O_6$ (solid) 18% as $Ca_3(PO_4)_2$ (solid) 7% as CaO (slag/silicate melt)	21% as $CaMgSi_2O_6$ (solid) 12% as $CaSiO_3$ (solid) 65% as SiO_2 (slag/silicate melt)	99% as SO_2 (gaseous) 1% as SO_3 (gaseous)

Table 4
Input data for boiler-house reconstruction feasibility assessment.

Variable	Parameter	Dimension	Value/calculation formula
Input data			
a1	Average heat capacity	MW	2.50
a2	Annual hours	h/year	8000
a3	Average annual rate of load	%	91
a4	Fuel used before the renovation	NG	Natural gas
a5	Average calorific value of fuel before the renovation	kcal/kg	11,751.6
a6	Coefficient of efficiency before the renovation	–	0.92
a7	Fuel used after the renovation	Fuel	Straw biomass
a8	Average calorific value of fuel after the renovation	kcal/kg	1875.3
a9	Coefficient of efficiency after the renovation	–	0.79
a10	Currency	EUR	Thousand EUR
a11	Total estimated investment	Thousand EUR	971.0
a12	Loan interest rate	%	8.0
a13	Discount rate	%	9.0
a14	Year of initial investment	Year	2012
a15	Credit period	Years	8
a16	Fuel price per 1 t before the renovation	EUR thousand	1.821
a17	Fuel price per 1 t after the renovation	EUR thousand	0.140
a18	Operating costs per 1 MW h produced before the renovation	EUR thousand	0.005
a19	Operating costs per 1 MW h produced after the renovation	EUR thousand	0.017
a20	Inflation rate (for a16, . . ., a19)	%	2.0
Introductory information			
b1	Annual heat production	MW h	$a1{\cdot}a2$
b2	Fuel consumption before the renovation	t	$(b1/a6){\cdot}(3.6/0.004186{\cdot}a5)$
b3	Fuel consumption after the renovation	t	$(b1/a9){\cdot}(3.6/0.004186{\cdot}a8)$
b4	Expenditure on fuel before the renovation	EUR thousand	$b2{\cdot}a16{\cdot}(1+a20/100)^{n-1}$
b5	Expenditure on fuel after the renovation	EUR thousand	$b3{\cdot}a17{\cdot}(1+a20/100)^{n-1}$
b6	Maintenance expenditure before the renovation	EUR thousand	$b1{\cdot}a18{\cdot}(1+a20/100)^{n-1}$
b7	Maintenance expenditure after the renovation	EUR thousand	$b1{\cdot}a19{\cdot}(1+a20/100)^{n-1}$
b8	Offsets in a cap-and-trade system	EUR thousand	0
Cash flow planning			
c1	Investment expenditures	EUR thousand	$a11{\cdot}(-1)$
c2	Production activity (incomes/expenditure)	EUR thousand	$(b4+b6)–(b5+b7)+b8$
c3	Amount of the debt (expenditure)	EUR thousand	$c3{\cdot}(-1)$
c4	Cash flow	EUR thousand	$c2+c3$
c5	Discount factor	Number	$1/(1+a13/100)^n$
c6	Discounted cash flow (DCF)	EUR thousand	$c4{\cdot}c5$
c7	Project balance	EUR thousand	$c7_{(\text{last year})}+c6$

n = number of years the HOB is under the exploitation.

6.2. *Bioenergy status in 52 districts of Lithuania – status quo and outlook to 2020*

The vision of the DH sector is to increase energy efficiency in the heat production, distribution and consumption while at the same time shifting from mainly natural gas (NG)-based production towards solid biofuels [1]. Currently there are about 200 biofuel boiler-houses in Lithuania (installed capacity about 500 MW) located approximately in 24 districts. Firewood and wood waste are the most used source of energy, which accounted for 38% of total household energy consumption; centrally supplied heat accounted for ~33%, electricity ~14%, NG ~9%, liquefied petroleum gas ~3%, coal ~2%, agricultural waste, peat fuel and peat briquettes ~1%. Household expenditure (HHE) on heat accounted for ~47% of total HHE on fuel and energy; HHE on electricity accounted for 31%, NG ~9%, firewood and wood waste ~8% of total HHE on fuel and energy [40]. An overview on biomass-firing HOB units that are already in operation is given in Fig. 3.

Households (HHs) are among the major energy consumers in Lithuania. According to the household energy consumption survey data, in 2009, the energy consumed in the dwellings owned by HHs accounted for about 31% of final energy consumption in the national economy. Citing [40], 81% of energy was consumed by HHs for space heating and hot water preparation. The average amount of energy consumed per household (year: 2009) amounted to 13,590 kWh. Private houses (PHs), on average, consumed 18,360 kWh of energy, while apartments in the blocks of flats (ABF) – 10,650 kWh. The average heated area of a dwelling (ABF and PHs are taken in conjunction) amounted to 74 m^2 in rural areas.

In 2009, the energy consumed for heating a dwelling amounted, on average, to 9650 kWh, which accounted for 71% of total household energy consumption [40]. Having considered that the heating in Lithuania lasts for about 4800–5100 h/year (depending on region and specific conditions in particular region), the heating of an area of 1 m^2 of a dwelling during the heating season required around 153 kWh of energy. As determined in [40], almost 30% of all dwellings are located in rural areas (districts, municipalities or elderships): 82% of dwellings are PHs, 18% – ABF.

The review of market potential is based on existing information on current use of HOBs, available biofuels, projected demand for heat (including population density, population per district, area per district), and availability of energy efficient HOB technologies.

The situation in Lithuanian DH sector is very different. In the year 2010, 12 districts (23.1% of total number) of 52 had a biomass share equal to or exceeding 40% of the annual fuel (mainly NG) consumption (see Fig. 3) in particular region. Statistics for the remaining 40 districts is as follows: 2 districts (3.85% of total number) having 30–40% of biomass share, 5 (9.6% of total number) – 10–20%, 5 (9.6% of total number) – less than 10%, and 28 (53.85% of total number) – 0% or non-appreciable share, i.e. ~1%.

Taking into consideration country's future ambitions to reach biomass share for DH of about 30–40% (of total fuel's cake for heat production) in 38 districts, the following growth of biomass

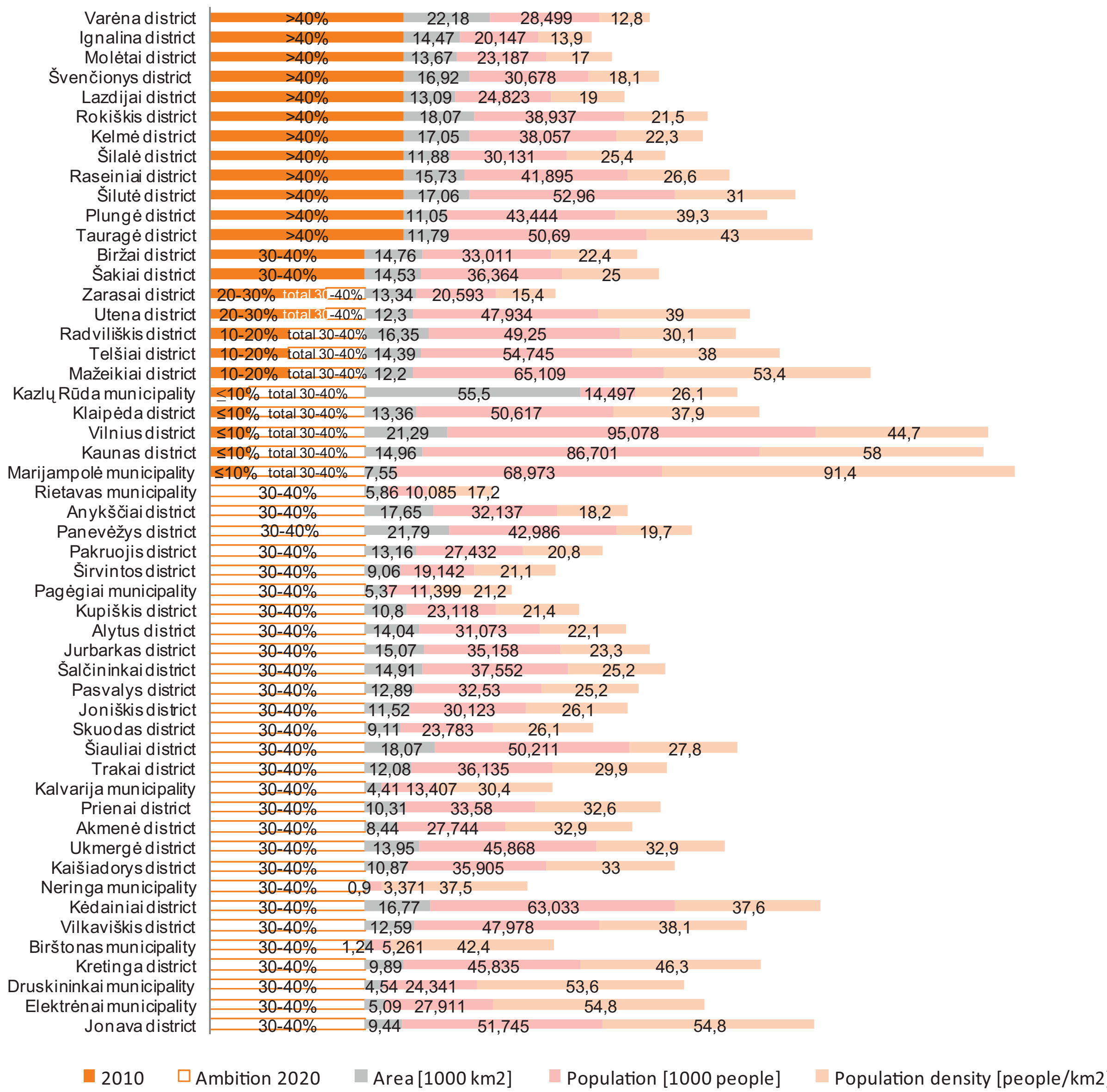

Fig. 3. Exploration of biomass-firing technologies and site features for districts of Lithuania.

contribution could be expected over the next decade: 28 districts – 'start from scratch' or growth rate exceeding 3000–4000% (assuming that current share of bioenergy is 1% of total energy consumption in the particular district), 5 districts – ≥200–300%, 3 districts – 200–100% and 2 districts – 50–33% (see Fig. 3). The Lithuanian Biomass Energy Association has calculated that in order to reach 70% of heat from renewable energy sources within the dwelling sector, it is necessary to readjust 1.5 GW of the existing installations [41]. In this case, only the multi-fuel approach (including significant share of biomass straw) can help to reach this target [33].

6.3. Agricultural land's availability

The review of prime agricultural land in Lithuania is a part of an extensive study which is aimed at integration of biomass straw in country's DH sector. The study was undertaken with the following objectives: (i) introduce potential operators of HOBs with an existing agrarian land-use in Lithuania, with an emphasis on forecasting of straw availability, and (ii) assess current level of agrarian land's urbanization level with the help of existing techno-morpho-topes (areas with a homogenous land-use structure and techno-structural elements) analysis.

Of the 6.5 million ha of land in Lithuania, the utilized agricultural area (UAA) is 3.5 million ha (i.e. 54% of the whole country's territory); arable land accounts for 2.95 million ha or 84.1% of UAA. A high proportion of the arable land is in forage cropping (44% of total crop area). About 50% of the UAA land is planted with cereals. Some land within the UAA is now abandoned and this has been estimated at 0.4 million ha (11.4% of total UAA).

The technosphere of agrarian land (relatively been divided into agricultural land, and conditionally less or rare technologically influenced agrarian areas – see Table 5) is best reflected by technogenic processes that comprise urbocomplexes (industrial areas and/or settlements), infrastructure and land use [42]. Actually, areal technologization of agrarian land plots is dominated by AUA areas of medium size (21.65%) and small VA areas (59.8%), thus doing biomass straw logistics acceptable for a lower-cost as an easy to spread in the regions. Urban complexes of the categories VA (39.6%) and HA (44%) are dominated amongst the conditionally less or rare

Table 5
Agrarian land's urbanization level and land-use types grouped using the techno-morpho-topes (T-M-Ts) classification [37].

Dominating land-use type[a]	Type of the urban complex dominating by area					
	Very large (>300 ha)	Large (300–150 ha)	Medium (150–50 ha)	Small (50–2 ha)	Very small (<2 ha)	No settlement (<0.5 ha)
Agricultural land plots	23 (HUA)	54 (HUA)	263 (AUA)	727 (VA)	148 (HA)	– (HA)
Conditionally less or rare technologically influenced agrarian areas	1 (HUA)	5 (HUA)	8 (AUA)	36 (VA)	40 (HA)	1 (HA)

[a] The distinguished types of techno-morpho-topes areal technologization: HUA – highly urbanized agrarian, AUA – averagely urbanized agrarian, VA – village agrarian, HA – homestead agrarian.

technologically influenced agrarian plots. The introduction of the technosphere into agrarian areas comprises 2.3% of UAA (or 2.7% of total arable land). As can be seen, it has very little influence in regard with total agricultural land's availability or impact on reduction in cereal crop plantations, though those two sources data have never been presented or discussed in a colligated form before, to make an overall picture.

6.4. Local straw market and installed capacities

Currently, Lithuanian Biomass Energy Association consists of 39 member companies including developers of biomass energy plantations and suppliers of solid biofuel. Due to low demand and lack of experience working with agricultural wastes providers, only a few companies in country could agree for long-term contractual obligation to supply quality biomass straw as a fuel for 1–5 MW_{th} capacity HOBs. Depending on straw quality, the price for baled straw could vary from 40.58 EUR/t to 52.17 EUR/t (year: 2011) with a tendency of higher price for large 1 t rectangular bale because of more energy consuming process for gathering and pressing. Contrary to existing practice in European countries, in Lithuania, about 90% of the collected straw is pressed using round baling presses. This is of the specific market situation nearly a decade ago, when a long-term support program grants for farmers released from EU funds initiated drastic increase in agricultural equipment purchase level, including mass acquisition of the round bailing presses for combine harvesters dominant in the market at that time for their lower price and locally established agricultural practice.

The potentially massive opportunity of replacing gas-fired appliances with straw-burning HOBs has largely been untapped. The first straw-fuelled HOB of 1 MW_{th} capacity has been installed in Narteikiai village (Pasvalys district) since 1996 (Table 6). Unfortunately, due to the regular ups and downs of NG prices during period 1996–2005, further introduction of fully automatic straw-fired technologies has been under consideration. In this period, only marked development for small-scale boilers (50–375 kW_{th}) was observed in Lithuania, mainly in family farms and pig farms. The second pattern of successful straw-fired HOB installation (Akademija town; year: 2007), having total capacity of 2.5 MW_{th} (2×1.25 MW_{th}) has been considered as the biggest one up till today.

6.5. A critical apprise of the challenges that affect sustainability

The incremental costs of energy efficient HOBs over conventional alternatives are significant, and usually present a disincentive to facility owners despite favorable life-cycle economics of the replacement. At present, the initial investment needs are a key factor in shaping the market potential, despite quality and performance gains [43].

The district heating segment in Lithuania for the bigger part is dominated by Russian-made boilers; their service life ranges from 12 to 25 years. Examples of typical HOB retrofit projects in Lithuania and elsewhere in the Baltic region indicated that investments in the mid range of heat-only boilers of 1 MW_{th} capacity would be recovered in approximately 3–5 years depending on the type of the installed system, its modification (standard 1 MW_{th} boiler or 2×0.5 MW_{th} boilers to enhance security of heat supply), demand for new premises, etc. In larger systems however, where the HOB size is ~2–5 MW_{th}, the simple payback period stretches to a 4–6 year range. Only imported brands (mainly Danish) currently exist in both size categories, thus increasing an investment risk for the expensive HOB units as well as reducing straw biomass competitiveness among solid biofuels, especially wood waste. As with most tradable commodities, the value of straw fuel also depends on supply availability and demand. One of the main contributory factors to the availability is the weather conditions in a given year. Poor weather conditions can lead to lower yields, and hence higher demand and prices.

Table 6
Installed capacities of straw fired boilers in Lithuania in the period 1996–2011.

Boiler house	Boiler units, pcs.	Boiler capacity, MW	Total capacity, MW	Year of installation
Pasvalys district (Narteikiai village)	1	1.0	1.0	1996
Pasvalys district (Grūžiai village)	1	0.375	0.375	1997
Pasvalys district (Vaškai town)	1	0.375	0.375	1997
Pasvalys district (Lavėnai village)	2	0.375	0.75	1997
Šilutė district (Juknaičiai settlement)	4	0.340	1.36	2000
Jonava district (Kuigaliai village)	1	0.340	0.340	2002
Šakiai district (Gelgaudiškis town)	4	0.460	1.84	2007
Kaišiadorys district	1	1.0	1.0	–
Family farms (in various locations)	~30–35	~0.05	~1.6	1998–2006
Pig farms (in various locations)	5	0.340	1.7	2000–2006
Kaunas district municipality (Akademija town)	2	1.25	2.5	2008
Panevėžys district municipality (Panevėžys city)	1	16 (straw share: 5% (~0.8 MW) of total biofuel demand)	16 (0.8)	Under installation (2010–2012)

Table 7
Life cycle assessment of 2.5 MW_{th} capacity boiler-house using straw as a fuel.

Years of implementation		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Number of years		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Introductory information																
Annual heat production	MW h		20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Fuel consumption before the renovation	t		1590.9	1590.9	1590.9	1590.9	1590.9	1590.9	1590.9	1590.9	1590.9	1590.9	1590.9	1590.9	1590.9	1590.9
Fuel consumption after the renovation	t		6360.1	6360.1	6360.1	6360.1	6360.1	6360.1	6360.1	6360.1	6360.1	6360.1	6360.1	6360.1	6360.1	6360.1
Expenditure on fuel before the renovation	EUR thousand		856.8	873.9	891.4	909.3	927.4	946	964.9	984.2	1003.9	1024	1044.4	1065.3	1086.6	1108.4
Expenditure on fuel after the renovation	EUR thousand		343.8	350.7	357.7	364.9	372.2	379.6	387.2	394.9	402.8	410.9	419.1	427.5	436.1	444.8
Maintenance expenditure before the renovation	EUR thousand		28.6	29.1	29.7	30.3	30.9	31.5	32.2	32.8	33.5	34.1	34.8	35.5	36.2	36.9
Maintenance expenditure after the renovation	EUR thousand		102	104	106.1	108.2	110.4	112.6	114.9	117.2	119.5	121.9	124.3	126.8	129.4	131.9
Offsets in a cap-and-trade system	EUR thousand		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash flow planning																
Investment expenditures	EUR thousand	−971														
Production activity (incomes/expenditure)	EUR thousand		439.5	448.3	457.3	466.4	475.8	485.3	495	504.9	515	525.3	535.8	546.5	557.4	568.6
Amount of the debt (expenditure)	EUR thousand		−77.7	−72.3	−66.5	−60.3	−53.5	−46.2	−38.3	−29.8	−20.6	−10.7	0.0	0.0	0.0	0.0
Cash flow	EUR thousand	−971	361.9	376	390.8	406.2	422.3	439.1	456.7	475.1	494.3	514.6	535.8	546.5	557.4	568.6
Discount factor	number	0.92	0.84	0.77	0.71	0.65	0.6	0.55	0.5	0.46	0.42	0.39	0.36	0.33	0.3	0.27
Discounted cash flows (DCF)	EUR thousand	−890.8	304.6	290.4	276.8	264	251.8	240.2	229.2	218.7	208.8	199.4	190.5	178.3	166.8	156.1
Project balance	EUR thousand	−890.8	−586.3	−295.9	−19.1	244.9	496.7	736.9	966.0	1184.8	1393.6	1593	1783.5	1961.8	2128.6	2284.7

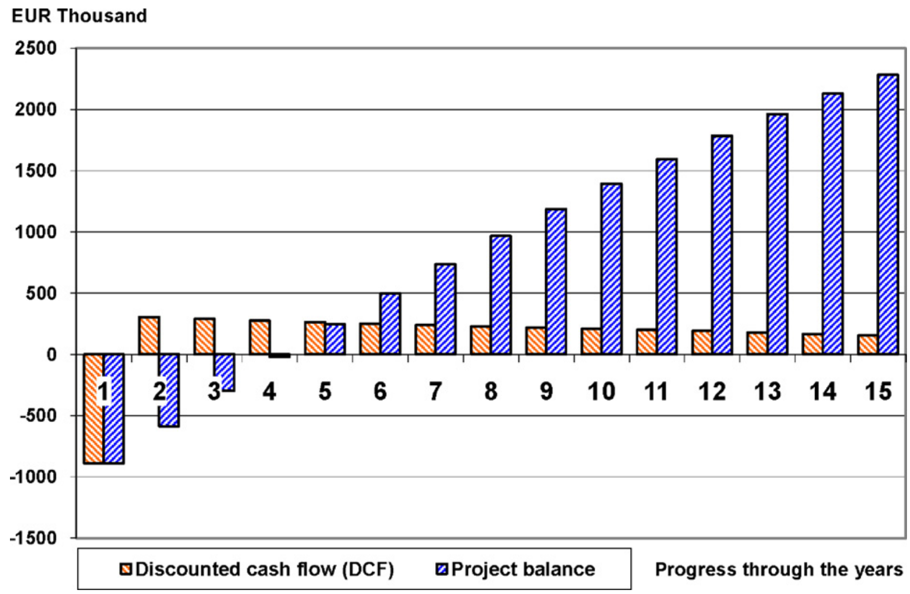

Fig. 4. DCF vs. Project balance for 2.5 MW_{th} straw-firing boiler-house.

6.6. Economic cost-benefit analysis (CBA) for small-scale production

The most of district heating companies in Lithuania are owned by co-operatives of house owners or municipalities. DH prices are regulated in a way that limits profits and which do not allow for the HOB utility to save up for investments [44]. On the other hand it is relatively easy for a DH company to obtain financing on good terms because the security of repayment is high; in some cases the municipality provides the collateral for investment by a co-operative. Consumer's ability to pay is also satisfactory. Within some restrictions a municipality might force connection to DH systems if so desired, but this is not always considered necessary or politically acceptable. At present there are no direct subsidies for small-scale biomass-firing plants investments [44].

In this section, we turn to a wider plant's perspective of 15 years period. Applying economic CBA, we reviewed the profitability of the straw-firing HOB of 2.5 MW_{th} capacity based on Danish technology (Tables 4 and 7). The review uses second quarter of the year 2011 as representing performances and current costs in fixed prices. A CBA yields a limited number of monetary indicators. These were distinguished into two types: pure monetary indicators, and unit cost indicators. Unit cost indicators are quantity divided by a functional unit which serves as a common basis through which projects can be compared and judged [39]. The economic CBA ignores all subsidies in order national financing institutions could make necessary supplement in renewable energy planning strategies.

In the context of a single HOB project evaluation, the applied discount rate has a unique value. However, depending on the viewpoint of evaluator (national society, private enterprise), large differences in its magnitude may occur [39]. The discount rates for private enterprises are equal to their perceived opportunity cost of capital, and they differ from enterprise to enterprise. They are, even after corrections for anticipated inflation, also strongly determined by the country in which a enterprise is located, mainly due to risk perceptions. Notwithstanding the fact that private enterprises in industrialized countries typically apply discount rates of about 12–15%, many researchers vote for using discount rate of 9% for appraisal of heat generation technologies in the context of marketing research studies [45,46]. A discount rate of 9% per year in current prices and the inflation rate of 2% per year indicates a real discount rate of 6.86% per year, i.e. $(100+9)/(1+2/100)-100=6.86$ [40].

In investment finance, discounted cash flows (DCF) analysis is a method of valuing projects. Accordingly, judging by DCF against project balance (Fig. 4) diagram and financial profitability indicators (Table 7), the plant is profitable. All future cash flows are estimated and discounted to give their present values – the sum of all future cash flows, both incoming and outgoing. The pay-back period is 4.1 years. For 15 years of HOB's operation the internal rate of return under described conditions is 40.6%. Citing [46], by scaling up the boiler-houses, the variations of the financial parameters become less sensitive to the critical variables affecting the economic profitability of the straw-fired HOBs. However, the quantity of fuel required is a function of scale, and to ensure a secure biomass straw supply, smaller scale boiler-houses may be more practicable in the context of Lithuania.

7. Conclusions

In some applications, agricultural waste in the form of biomass straw could reasonably counterweight firewood and wood waste for heat production in Lithuanian DH sector. Straw-firing HOBs named as a high potential alternative for thermal energy generation instead of field burning, which is a waste of renewable resources having negative impact to local pollution.

In comparison to large industrial countries, cereal production in Lithuania is not limited by availability of agricultural land in terms of total extent of usable land; in terms of crop rotation needs, and in terms of competition with other crops. Burning of agricultural residues in the automatically fired HOBs can contribute significantly to switch from natural gas to local biofuel (Fig. 3). The driving forces are the CO_2 neutrality of sustainable cultivated cereal grain (wheat and barley) and the utilization of agricultural residues. By introducing available knowledge in practice, problems related to straw combustion (Table 3) can be overcome, thus having a big potential for better economy in DH sector, reduced environmental impact as well as increased propagation by solving country's energy independency problems.

Under conditions in Lithuania's DH sector, biomass straw combustion is prospective mainly to be used for heat production in

small and medium scale units of 0.6–5.0 MW_{th} capacity. In the big cities, lignocellulosic crop residues could be applied in large scale installations where multi-biomass strategies are foreseen, as presented in Table 6 (95% of wood residues + 5% of biomass straw).

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